2020 DOE Vehicle Technologies Office Annual Merit Review Presentation

"Next Generation Intelligent Traffic Signals for the Multimodal, Shared, and Automated Future"

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Xtelligent
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Project ID: eems069

Overview

Timeline:

- Project start date: September 2019
- Project end date: August 2021
- Percent complete: 40%

Funding:

- Total project funding: $1,000,000

Partners:

- Argonne National Laboratory (ANL)
- City of Greenwood Village, CO
- City of Fremont, CA
- Colorado Dept of Transportation (CDOT)
- Los Angeles Cleantech Incubator (LACI)

Barriers to achieving objectives:

- COVID19-related significant reduction in vehicle movement and congestion (-60%) causing temporary delay in performance measurement
- Real-world validation required of Proportionally Fair (PF) Adaptive Traffic Control System (ATCS) algorithm on the network-level (beyond intersection-level).
- Availability of viable location data as additional input to Xtelligent's PF ATCS system.
- Computational difficulty of modeling energy efficiency and greenhouse gas (GHG) improvements across cities.

Relevance and objective

Relevance:

1. Improve energy productivity of the overall transportation system:
    - Advanced Proportionally Fair (PF) Adaptive Traffic Control System (ATCS) algorithm can dramatically increase systems-level energy efficiency (>50% improvement achieved in PTV VISSIM microsimulations).
2. Improve affordability:
    - Incorporation of location data streams from internet-based sources in combination with PF ATCS can also dramatically increase affordability of transportation systems by avoiding installation of costly physical sensor infrastructure.
3. Research and Develop an ATCS system with true product-market fit
    - 40 yrs of ATCS systems have failed to penetrate U.S. traffic signals market beyond 1-2%
        - Incumbent systems have been cumbersome, expensive, and failed to achieve marketed benefits, frustrating two generations of transportation professionals.

Objectives:

- Real-world, in-street research of PF ATCS algorithm to improve energy efficiency of transportation network by retiming traffic signals in real-time. Incorporate novel location data streams as inputs to dramatically reduce cost for cities, counties, and states to adopt these systems.
    - Phase I resulted in basic prototype PF ATCS that showed 21% improvement in single-intersections.
    - Phase II focuses on expansion to corridor control, bigger road network, and inclusion of streaming location data
    - Conduct pre/post data analysis with ANL to validate energy efficiency gain of vehicles on associated streets (initial estimate by ANL = **15% energy efficiency gain** and proportional greenhouse gas emissions reduction)
    - *Test additional use of streaming location data from connected vehicles and other location data systems.

Relevance: Achieved through April 2020

- Achieved:
  - Phase I single-intersection system refactored to function on corridors
  - 19 separate in-road system tests performed to iterate system development
  - Myriad hurdles overcome interfacing with legacy traffic signal controller infrastructure
  - Basic user interface proof of concept completed
  - Streaming data providers evaluated, though not yet integrated
- Pending:
  - Performance testing of full corridor-enabled PF ATCS system (delayed due to COVID19*)
  - Complete Objective 2. See GANTT →
  - Complete additional objectives

Current quarter

Phase II *Proposal* GANTT Chart*:

Milestone	**Deliverables**	**Year 1** Q1: 09DEC19	Q2: 09MAR20	Q3: 09JUN20	Q4: 09SEP20	**Year 2** Q5: 09DEC20	Q6: 09MAR21	Q7: 09JUN21	Q8: 09SEP21
Objective 1: Coordinated ATCS Control for Throughput Maximization	Backend design for intersection-to-intersection communication								
	Installation and configuration of each								
	Activation and performance monitoring								
	Continuous improvement iterations								
Objective 2: Evaluation of Data Streams	Data quality analysis for each data source								
	OEM(s)								
	TomTom								
	INRIX								
	Waze Connected Citizens Program								
	Xtelligent mobile phone application								
	Other								
	Data source preference hierarchy determination								
	Data source logic implementation for queue calculation								
Objective 3: Performance Improvement by <u>Supplementing</u> Existing Physical Sensor Data with Connected Vehicle Location Data (V2I using 4g/LTE)	Software/algorithm encoding to incorporate location data on streaming basis								
	Activation and performance monitoring								
	Continuous improvement iterations								
Objective 4: ATCS Control Using Connected Vehicle Data <u>Only</u>	Software/algorithm encoding to incorporate location data on streaming basis								
	Activation and performance monitoring								
	Continuous improvement iterations								
Objective 5: Evaluation of Beta/Pilot	Internal evaluation								
	Independent validation								

*Delays due to COVID-19 are further discussed later in presentation

Approach: Summary of overall technical approach

Three steps:

1 Integrate Proportionally Fair algorithm (PF) into a live Adaptive Traffic Control System (ATCS) across corridors and grids, using traditional physical vehicle detection sensors. Test performance against baselines.*

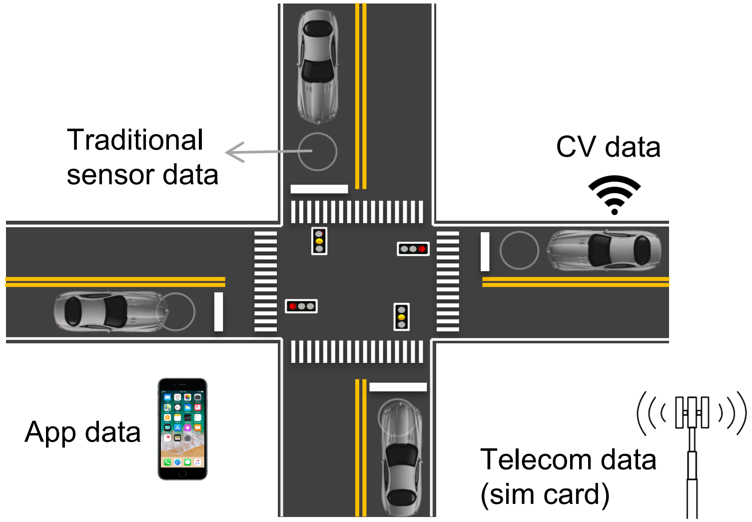
2 Augment step 1 with streaming vehicle location data from Connected Vehicles (CVs), cellular devices, or other systems to improve system awareness of vehicle locations and improve performance. Test performance against baselines.

3 Remove traditional physical sensor data stream and rely solely on streaming location data. Test performance against baselines.

PF ATCS algorithm basics

- Inspired by well-regarded controllers from communications networks
- Sets each phase's green time allocation in proportion to its share of aggregate demand
- Practical for real-world use:
    - Does not require turning ratios
    - Only requires aggregate phase queue length
    - Does not need downstream queue lengths

Vehicle presence detection data types



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Technical accomplishments and progress: history

<u>Final work under Phase I (not reported in last year's AMR presentation:</u>

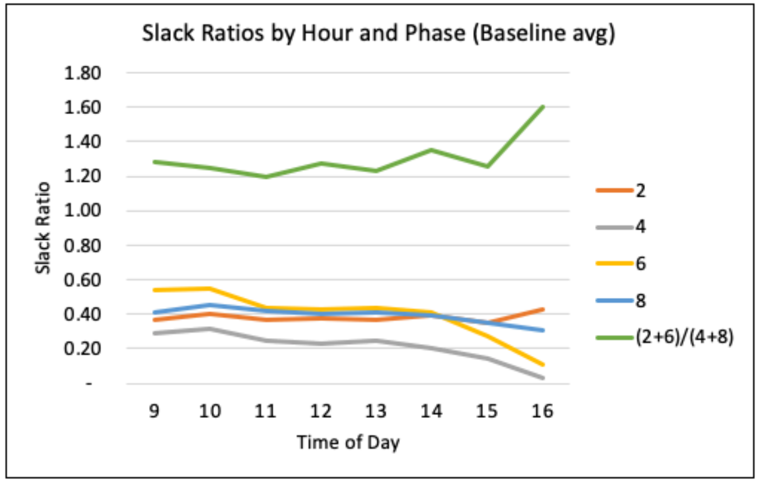
At the end of Phase I, Xtelligent was able to demonstrate successful implementation of its PF ATCS solution in single, non-coordinated environments.

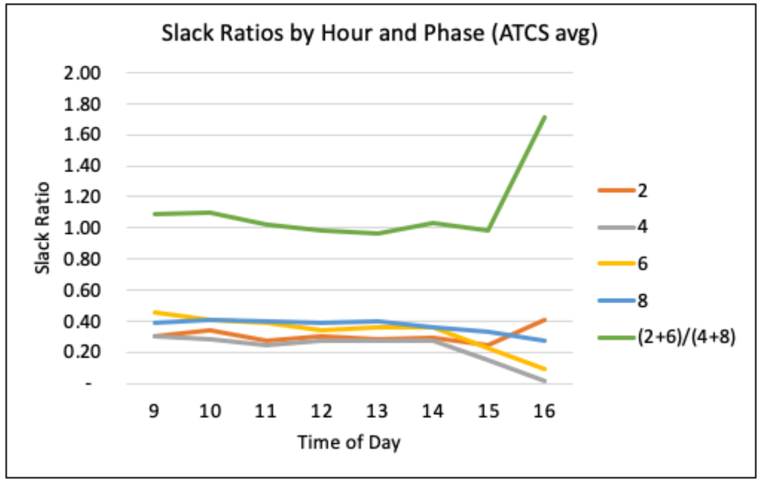
Because single-intersections effectively represent a network of one node, we use green-time utilization (or the inverse, "slack ratio") as the representative metric.

Green-time utilization is the percent (%) of green-time utilized, and is correlated to throughput and traditional transportation metrics like travel time, delays, arrivals on red, level of service, etc.

Key focus was ratio of green-time utilization between major through-phases (2 and 6) and side phases (4 and 8). Perfect balance would be indicated by a Slack ratio of 1.00

0.21 or 21% improvement achieved





Data includes 1,240 cycles and 2,074 ATCS cycles

<u>Baseline</u>

- "Slack ratio" represents proportion of green time not utilized
- Most phases exhibited 0.40 unused greentime
- Ratio of main phases to side phases (2+6)/(4+8) = 1.30

<u>PF ATCS</u>

- Ratio of main phases to side phases (2+6)/(4+8) = 1.09
- ***21% improvement***
- **Tests deactivated daily at 1600. Spike at 1600 due to restoration of city control

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Technical accomplishments and progress: snapshot

Phase II *Proposal* GANTT Chart:

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Status

- Completed
- Completed
- **COVID-19 traffic impact -60%
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- First set of data source evaluations completed. This will be an ongoing effort
- See slide 9
- See slide 9

On track/not applicable yet

- All performance evaluations delayed due to COVID19 reduced traffic

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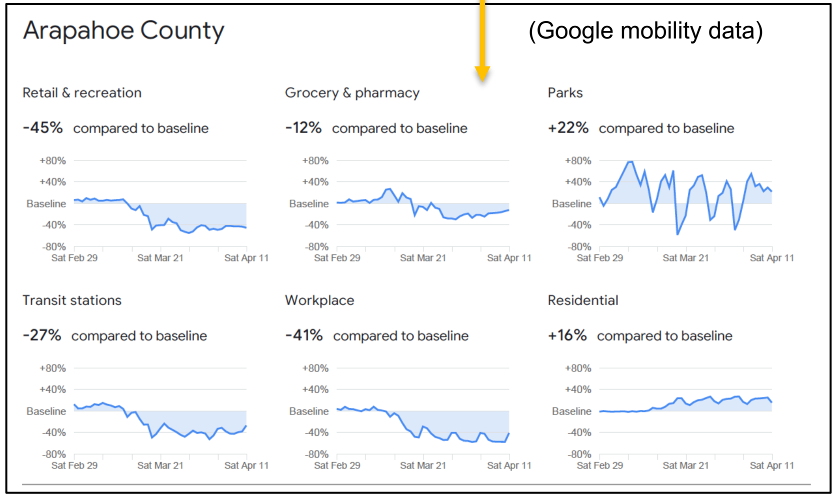
Technical accomplishments and progress: ATCS update

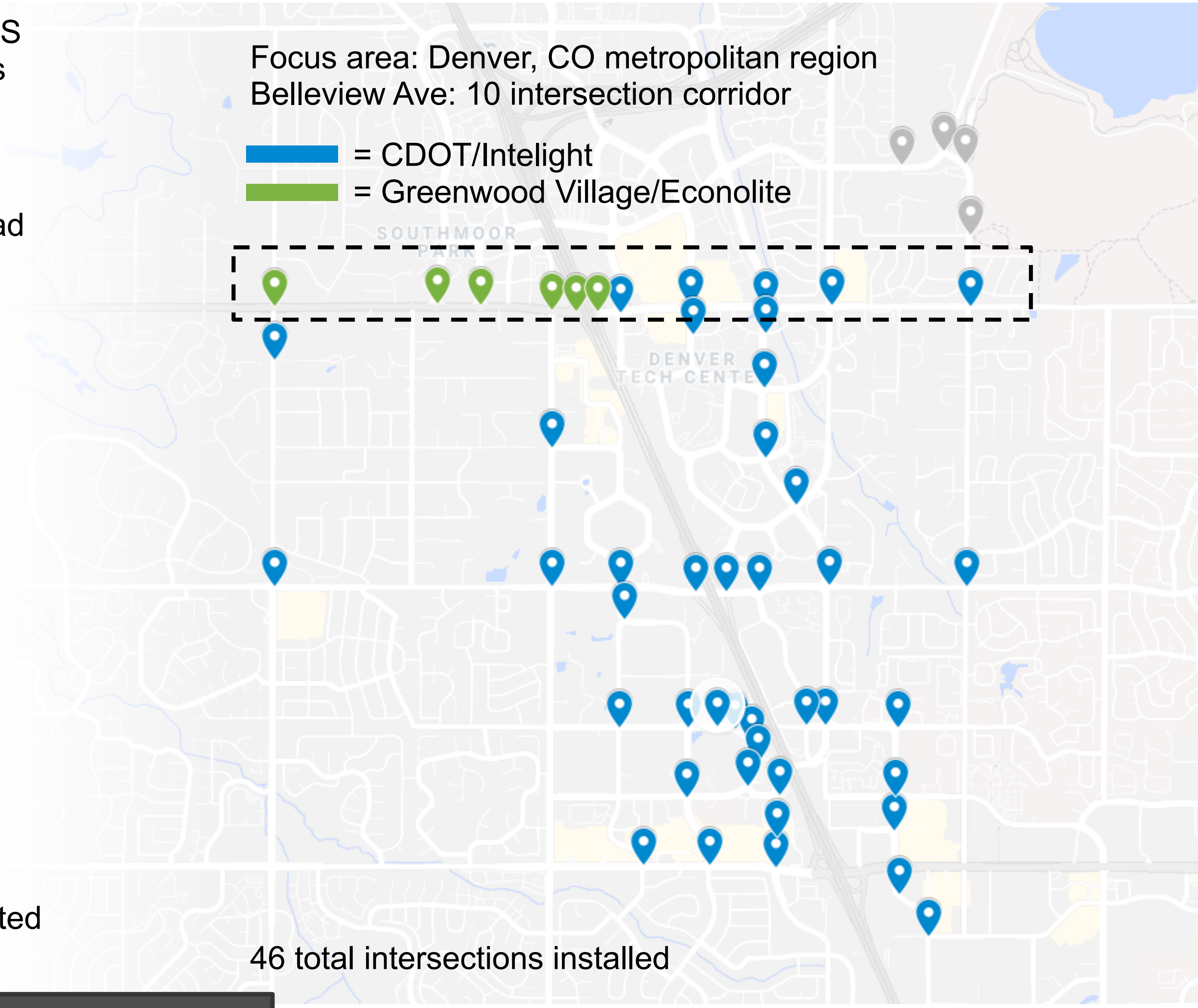
As of mid-April 2020, Xtelligent has successfully built its PF ATCS system to operate in both corridors and single intersections. This was a significant hurdle that we underestimated.

Although working with the "standardized" NTCIP Management Information Base (MIB) to interact with existing controllers, myriad differences exist between each controller manufacturer's interpretation of this standard.

Performance testing has been delayed due to COVID-19 related traffic volume reductions



11 intersections are also installed in Fremont, CA and will be tested concurrently with the Colorado evaluation



System is ready for testing!

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Technical accomplishments and progress: data update

- Xtelligent has been aggressively pursuing location data partnerships in preparation for integration of these data streams into its PF ATCS test bed.
- Key variables for each data stream are % penetration, % accuracy, data latency, and ease of partnership.
- Due to non-disclosure agreements, all names must remain obscured.
- GDPR and similar data privacy considerations have resulted in protracted discussions.
- Not all data partners will be utilized – only those with technical potential to augment PF ATCS system.
- Preferred data streams appear to be 1-4 and 5.

	Data partner	% Penetration (of vehicles)	Accuracy	Latency	Partnership potential
1	Connected Vehicles: OEM 1	<1%	2m	30 sec	Medium
2	OEM 2	<1%			Medium
3	OEM 3	0-5%[1]			High
4	OEM 4	~4%			High
5	Telecom 1	30%	100m	>5 min[2]	High
6	Data Aggregator 1	10%	~50m	1-15 min[3]	Medium
7	Data Aggregator 2				Medium
8	Data Aggregator 3				Medium
9	Xtelligent's App	0%	2m	1s	High

1 Requires installation and connection of OEM's or 3rd party smart phone app
2 Expected to improve with time
3 Varies according to location and frequency of data points on specific links. Aggregators attempt to provide "smoothed" data to agencies, whereas we seek the raw data feed.

Data integration still early, but strong start to Xtelligent's evaluation of data options

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Technical accomplishments and progress: other work

One additional, significant, and unanticipated task has been undertaken during Phase II thus far:

- Conversion of hardware approach from installing an interface device at each intersection, to using a single, central hardware unit.

Why did we make this change?

1. Tremendous time sink managing all the units: → Pushing software updates, troubleshooting, etc. was consuming vast amounts of team time
2. Cellular connectivity wasn't required after-all: → All pilot-sites for Phase II research have network connection at the cabinet
3. Not necessary to have distributed computing: → Phase II research can be executed more efficiently and just as effectively with single hardware unit
4. Less cost: → One centralized unit can manage 10s or 100s of intersections, but is only 4X the cost of a single intersection unit

Current interface device unit
(Axiomtek IFB-122)

Central hardware unit
(Intel Nuc Cluster)

Expected to result in more efficient utilization of team's time

Responses to previous year's reviewer comments

1 Primary theme of comments from previous year's reviewers regarded metrics.

Comments:

- *"it is common practice to offer before and after analysis. Indicate what technology or type of traffic signal system/coordination plans were in place prior to this project."*
- *"This should be coordinated against actual Traffic Systems performance metrics. As an example, there is no mention of the crash history pre- and post-analysis."*

Response:

- Before and after analysis is critical to evaluating performance. These test-sites are utilizing actuated TOD systems, both coordinated and uncoordinated depending on location.
- When COVID-19 depressions in traffic volumes improve, Xtelligent will be testing performance with a few important considerations in place:
  - Two baselines: pre-test AND post-test to adjust for any movements in baseline or seasonality
  - Traditional and non-traditional metrics:
    - Traditional traffic metrics include level of service, delays, travel time, arrivals on red, arrivals on green, etc.
    - Non-traditional metrics: throughput and green-time utilization (see slide 6)

2 Other:

Comments:

- *"no details were provided on the algorithm"*

Response:

- Simple overview of PF algorithm provided on slide 5. For full detail see "Hosseini, Pouyan & Savla, Ketan. (2016). A Comparison Study between Proportionally Fair and Max Pressure Controllers for Signalized Arterial Networks."

Comments:

- *"it is not clear if these are true barriers to achieving objectives"*

Response:

- Barriers updated on Overview slide (2)

Collaboration and coordination with other institutions

- Project requires complex collaboration with city engineers, city IT network administrators, and traffic signal controller manufacturers. This collaboration has continued strongly as evidenced by our achievements thus far.

- Argonne National Laboratory is a subcontractor for final data analysis to estimate energy efficiency gains achieved by this ATCS approach as well as corresponding GHG emissions reductions. Data evaluation delayed until COVID-19 traffic volumes are restored.

- Fremont, CA is pilot site #1
- CDOT + Greenwood Village, CO is pilot site #2
- Long Beach, CA is in final stages of MOU to become site #3

LACI
FOR ENTREPRENEURS
BY ENTREPRENEURS

CDOT
CO

GREENWOOD VILLAGE
COLORADO

CITY OF
LONG
BEACH

CITY OF
Fremont

Remaining challenges and barriers

- COVID-19 traffic volume reductions are preventing valid performance analysis by eliminating relevant baselines and opening up vast amounts of roadway capacity. Current levels of traffic volumes are approximately 50-60% reduced from regular baselines
    - We have reprioritized tasks to push performance testing to the end of our grant timeline.

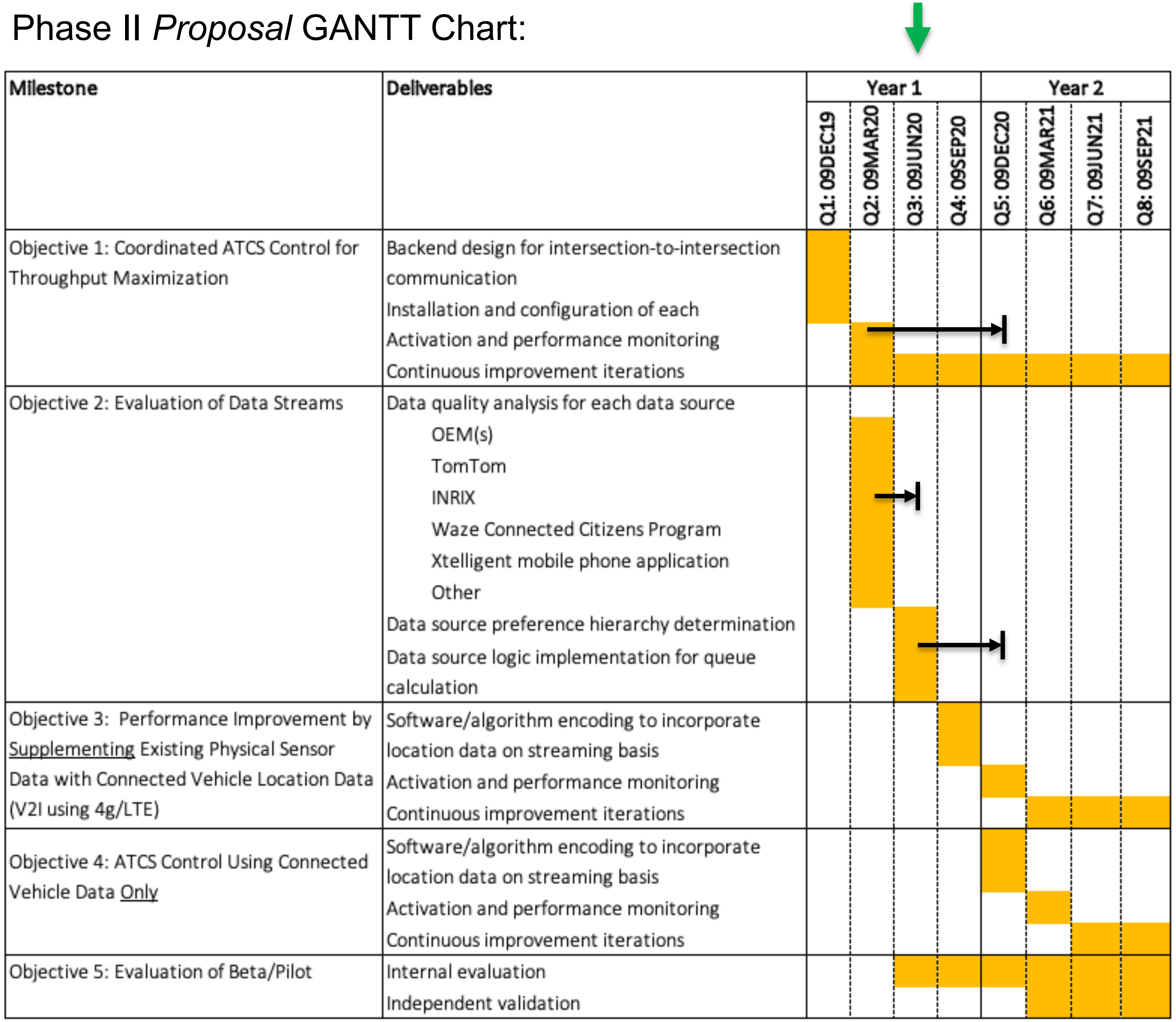
- As expected, no “slam-dunk” streaming location data provider found yet. This will require careful fusion of location data from multiple internet-based APIs (CVs, apps, telecoms, etc.). Doing this from a technical and business partnership standpoint is a complex task that our team is well suited for.
    - **Success against DOE VTO goals requires this system to significantly enhance energy productivity of the roadway and be affordable to transportation agency customers. Xtelligent is evaluating data with this requirement in mind.

- Commercialization into transportation agency purchasing market involves longer purchasing cycles, requirement for track-record, and entrenched players. This SBIR funding is critical to supporting Xtelligent to establish required track record for potential commercialization of the PF ATCS

Proposed future research

“Any proposed future work is subject to change based on funding levels.”

Phase II *Proposal* GANTT Chart:



Tasks	Completion Date
Conduct rigorous performance testing as soon as traffic volumes are restored post-coronavirus	Estimate Q4, 2020
Choose top 3 data sources and determine logic to integrate with traditional sensor data	Estimate Q3, 2020
Design and implement hybrid system	Estimate Q4, 2020
Test efficacy as compared to PF ATCS using traditional sensors	Estimate Q4, 2020
Design and implement, streaming location data input-only system	Estimate Q2, 2021
Post COVID-19	Estimate Q4, 2020+

Summary

- Xtelligent has spent the first seven months of the grant performance period preparing its system for coordinated and single intersection control:
  - Refactored system to implement desired offsets and splits along corridors
  - Integrated one corridor across 2 agencies on 2 separate networks with 2 types of controllers, 2 types of cabinets, and 2 central systems.
  - Redesigned system to utilize a single hardware unit for faster iteration

- Poised to start testing efficacy, but COVID-19 significantly reduced traffic volumes. Traffic volumes expected back up by fall. Testing will begin then.

- Per plan the team is now focusing on streaming location data evaluation and integration. This progress has been strong, though significant work remains for full integration.
  - Three data location partners will be chosen to proceed to implementation

- Xtelligent is committed to increasing energy productivity of transportation networks through its novel, PF ATCS controller optimization algorithm, while simultaneously and materially reducing the cost of such systems to transportation agencies